

Simulating the metal enrichment of the intra-cluster medium

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ABSTRACT

We present results from Tree+SPH simulations of a galaxy cluster, aimed at studying the metal enrichment of the intra-cluster medium (ICM). The simulation code includes a fairly advanced treatment of star formation, as well as the release of energy feedback and detailed yields from both type-II and type-Ia supernovae, also accurately accounting for the lifetimes of different stellar populations. We perform simulations of a cluster with virial mass $\simeq 3.9 \times 10^{14} M_{\odot}$, to investigate the effect of varying the feedback strength and the stellar initial mass function (IMF). Although most of the models are able to produce acceptable amounts of Fe mass, we find that the profiles of the iron abundance are always steeper than observed. The $[\text{O}/\text{Fe}]$ ratio is found to be sub-solar for a Salpeter IMF, with $[\text{O}/\text{Fe}] \simeq -0.2$ at $R \gtrsim 0.1 R_{200}$, whereas increasing to super-solar values in central regions, as a result of recent star formation. Using a top-heavier IMF gives a larger $[\text{O}/\text{Fe}]$ over the whole cluster, at variance with observations. On the other hand, the adoption of a variable IMF, which becomes top-heavier at $z > 2$, provides a roughly solar $[\text{O}/\text{Fe}]$ ratio. Our results indicate that our simulations still lack a feedback mechanism which should quench star formation at low redshift and transport metals away from the star forming regions.

Key words: Cosmology: Theory – Galaxies: Intergalactic Medium – Methods: Numerical – X–Rays: Galaxies: Clusters

1 INTRODUCTION

Measurements of the content and distribution of metals in the intra-cluster medium (ICM) provides invaluable insights on the interplay between the evolution of diffuse cosmic baryons and the past history of star formation. If supernovae (SN) had played a significant role in altering the thermal status of the ICM, then they should have left their imprint also on its metal content (e.g., Renzini 2003). The increasing capability of X-ray telescopes to perform spatially resolved spectroscopic studies of the ICM have opened in the last years the possibility of quantifying the metal content of clusters. Observations from ASCA (e.g., Baumgartner et al. 2003), Beppo-SAX (e.g., De Grandi et al. 2003), Chandra (e.g., Ettori et al. 2002; Blanton et al. 2003) and XMM-Newton (e.g., Gastaldello & Molendi 2002; Matsushita et al. 2003) have revealed that abundance gradients are quite common in clusters. Besides their distribution, the relative abundance of different metal species gives information on the role played by type-Ia and II SN in the ICM enrichment (e.g.,

Matteucci & Vettolani 1988; Pipino et al. 2002; Finoguenov et al. 2002; Portinari et al. 2003). Finally, the lack of any significant evolution of the Fe abundance at least out to $z \sim 1$ (Tozzi et al. 2003) demonstrates that the process of enrichment has been completed already at quite large look-back times. While the production of metals is connected to the activity of star formation, their distribution may be determined by different physical effects, such as ram-pressure stripping of metal-rich gas from merging galaxies or galactic winds powered by SN explosions and AGN activity (e.g., Gnedin 1998). Whatever the mechanism for metal transport and diffusion is, modelling the ICM enrichment requires a careful description of the yields and of the lifetimes of the different stellar populations associated to the different SN types (e.g., Matteucci 2001, and references therein). In this respect N-body simulations provide the ideal tool to describe in detail how metals are produced within galaxies and distributed during the hierarchical assembly of a cluster. Besides semi-analytical approaches (e.g. De Lucia, Kauffman

& White 2003), attempts to include, within hydrodynamical simulations, star formation, SN energy feedback and metal enrichment from type-Ia and II SN, have been pursued by different authors (Aguirre et al. 2001; Lia, Portinari & Carraro 2002; Valdarnini 2002; Kawata & Gibson 2003; Kobayashi 2003; Tissera & Scannapieco 2003). It is however clear that such approaches rely on the capability of the numerical codes to provide a physically sound description of the relevant “sub-grid” processes.

In this *Letter* we present the first results from our hydrodynamical simulations of clusters based on the implementation of chemical enrichment in the GADGET code (Springel, Yoshida & White 2001). Our chemo-dynamical version of GADGET combines the rather advanced treatment of star formation and SN feedback, proposed by Springel & Hernquist (2003a, SH03 hereafter), to a careful description of the role of type-Ia and II SN in releasing metal-enriched gas into the diffuse medium. In the following, when expressing the ICM metal abundances in solar units, we assume the photospheric abundance provided by Grevesse & Sauval (1998).

2 THE SIMULATION CODE

Our simulations are based on an evolution of GADGET* (Springel et al. 2001), a parallel Tree+SPH code with fully adaptive time-stepping. As a starting point, we used a version of GADGET, kindly provided by V. Springel, which includes an entropy-conserving integration scheme, radiative cooling, the effect of a uniform and evolving UV background (Haardt & Madau 1999), star formation from a multiphase interstellar medium and a prescription for galactic winds triggered by SN explosions (see SH03 for a detailed description). In the original version of the code, the energy release and a global metallicity was produced only by SNII under the instantaneous-recycling approximation (IRA).

The GADGET code has been suitably modified, so as to correctly include the life-times of different stellar populations, to follow metal production from both SNIa and II, while self-consistently introducing the dependence of the cooling function on metallicity. A detailed description of the implementation of these algorithms will be presented in a forthcoming paper (Tornatore et al. 2004, in preparation), while we provide here a short descriptions of the most relevant features of the code.

In order to maintain the general approach of the multiphase model by SH03, we still treat under the IRA stars with masses $> 20 M_{\odot}$, while accounting for the different life-times of stars of smaller mass (Matteucci & Padovani 1993). Within the stochastic approach to star formation (SH03), each star particle is considered as a single stellar population (SSP). For each SSP we compute the number of stars turning into SNII and Ia at each time-step after its creation.

The SNIa are associated to binary systems whose components are in the $0.8\text{--}8 M_{\odot}$ mass range (Greggio & Renzini 1983), while SNII arise from stars with mass $> 8 M_{\odot}$ (cf. also Lia et al. 2002, who adopt the lower mass threshold of $6 M_{\odot}$ for SNII). Besides SNe, which release energy and

metals, we also account for planetary nebulae (PN). They contribute to metal production, but not to the energy feedback, and are identified with those stars, not turning into SNIa, in the mass range $0.8\text{--}8 M_{\odot}$. We use the analytical fitting formulas for stellar yields of SNIa, SNII and PNe as provided by Recchi et al. (2001), and based on the original nucleosynthesis computations of Nomoto et al. (1997, using their W7 model), Woosley & Weaver (1995) and Renzini & Voli (1981). The formulation for the SNIa rate has been calculated as in Matteucci & Recchi (2001). Besides H and He, the current version of the code follows the production of Fe, O, C, Si, Mg, S, and can be easily modified to include other metal species. Once produced by a star particle, metals are spread over the same number of neighbours, 32, used for the SPH implementation, also using the same kernel. In this way, we find that 90 per cent of the metals are distributed within a gas mass of $5.4 \times 10^9 h^{-1} M_{\odot}$. We have verified that using a twice as large number of neighbors to spread metals results in a twice as large gas mass for metal mixing, while final results on the amount and distribution of metals (see below) are left almost unchanged. As for the energy release, each SN is assumed to produce 10^{51} ergs. Instead of assuming any specific value for the thermalization efficiency of the energy released by SN, we prefer to dump all the energy to the surrounding gas particles and leave to the simulation the computation of the radiation losses. Since the physical processes determining the actual SN efficiency are below the resolution scale of our simulations, the rationale behind our choice is to leave to the sub-grid multiphase model by SH03 establishing how much of this energy enters in regulating the star formation process. We normalize the IMFs in the mass range $0.1\text{--}100 M_{\odot}$. Owing to the uncertainty in modelling yields for very massive stars, we take yields to be independent of mass above $40 M_{\odot}$. While any uncertainty in the yields of such massive stars has a negligible effect for a Salpeter IMF (Salpeter 1955, S55 hereafter), their accurate description (e.g. Thielemann et al. 1996; Heger & Woosley 2002) is required when using a top-heavier IMF. We note that our scheme to distribute metals in the ICM does not include the effect of diffusion. Lia et al. (2002) included the effect of diffusion driven by SN blast waves (see Thornton et al. 1998) in their SPH simulations with chemical enrichment. Although this effect is quite important to describe the diffusion of metals within the interstellar medium, it is likely to play a minor role on scales above the typical resolution scale, $\sim 10 h^{-1} \text{kpc}$, of the cluster simulations that we are discussing here.

Our prescription to account for stellar evolution in the simulations implies a substantial change of the multiphase “effective model” by SH03. In this model, gas particles are assumed to have a cold neutral and a hot ionized phase in pressure equilibrium, the former providing the reservoir for star formation. We have modified the criterion, dependent on local density and temperature, to establish the relative amount of such two phases, so as to account for the gradual SN energy release, which modifies the temperature of the hot phase and the evaporation of the cold one. This means to include new energy terms in Eq.(10) of SH03, which describes the evolution of the internal energy of the hot-phase component, while making the cooling function dependent on local metallicity. The metal-dependence of cooling, that we introduce using the tables from Sutherland & Dopita (1993),

* <http://www.MPA-Garching.MPG.DE/gadget/>

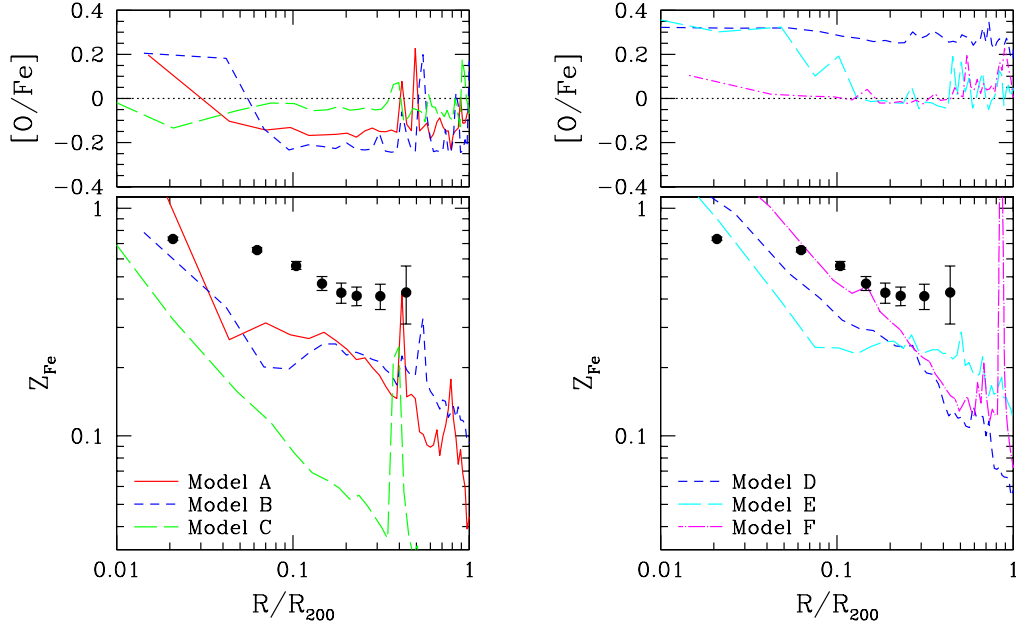


Figure 1. Profiles of the Fe abundance (lower panels) and of the $[O/Fe]$ relative abundance (upper panels) for the models described in Table 1. The points with errorbars in the lower panels show the observed average gradient of Fe abundance for cool-core clusters, as measured by De Grandi et al. (2003) from Beppo-SAX observations.

Table 1. Characteristics of the different runs. Col. 2: assumed IMF; Col. 3: wind efficiency; Col. 4: energy injection efficiency; Col. 5: average wind velocity (km s^{-1}); Col. 6: baryon fraction in stars within the virial radius R_{vir} ; Cols. 7–10: emission-weighted and mass-weighted ICM Iron and Oxygen abundances within R_{vir} (X/H , solar units); Cols. 11–12: fraction of total Iron and Oxygen masses, which are distributed in the diffuse ICM.

* The wind velocity for Model F refers to redshift range $z = 0-2$, while it increases at higher z , reaching $v_W \simeq 1100 \text{ km s}^{-1}$ at $z = 10$.

Run	IMF	η	χ	v_W	f_*	$Z_{\text{Fe}}^{\text{ew}}$	$Z_{\text{Fe}}^{\text{mw}}$	Z_{O}^{ew}	Z_{O}^{mw}	$f_{\text{Fe}}^{\text{ICM}}$	$f_{\text{O}}^{\text{ICM}}$
A	S55	2	0.5	520	0.20	0.55	0.11	0.70	0.09	0.39	0.18
B	S55	2	1	380	0.26	0.23	0.14	0.20	0.09	0.34	0.13
C	S55	6	3	520	0.12	0.15	0.05	0.13	0.05	0.23	0.13
D	AY	2	1	920	0.13	0.46	0.14	0.93	0.26	0.42	0.28
E	AY	2	0.3	530	0.24	0.29	0.18	0.4	0.21	0.26	0.10
F	FBB	2	1	600*	0.15	0.54	0.17	0.59	0.18	0.41	0.24

also enters in determining the onset of the thermal instability (eq.[22] of SH03) and the value of the density threshold for star formation (eq.[23] of SH03).

SH03 also provided a phenomenological description for galactic winds, which are triggered by SN energy release and whose strength is regulated by two parameters. A first one gives the rate of gas ejection by winds, according to the relation, $\dot{M}_W = \eta \dot{M}_*$, where \dot{M}_* is the star formation rate. The second one, determines the fraction of SN energy that powers the winds, $\frac{1}{2} \dot{M}_W v_W^2 = \chi \epsilon_{\text{SN}} \dot{M}_*$, where ϵ_{SN} is the energy feedback provided by the SN under IRA assumption for each M_\odot of stars formed. In our implementation of the winds, we also account for the energy contributed from all the SN treated without the IRA, namely SNII in the $8-20 M_\odot$ mass range and SNIa.

It is worth noticing that the star formation and SN feedback scheme, originally introduced by SH03, has been already demonstrated to provide the correct fraction of baryons locked in stars, the correct cosmic star formation history (Springel & Hernquist 2003b), the correct amount of neutral hydrogen in high column-density absorbing systems at high redshift (Nagamine et al. 2003), and to reproduce

the basic X-ray scaling properties of galaxy clusters (Borgani et al. 2003). As such, it represents a good starting point for a simulation study of the ICM chemical enrichment.

3 RESULTS AND DISCUSSION

We use our chemodynamical version of GADGET to run simulations of the Virgo-like cluster, which has been described by Tornatore et al. (2003). This structure is a fairly relaxed halo with a virial mass of $3.9 \times 10^{14} M_\odot$ and emission-weighted temperature of about 3 keV. It has been selected from a cosmological DM-only simulation of a flat Λ CDM model, with $\Omega_m = 0.3$, $\Omega_{\text{bar}} = 0.04$, $h = 0.7$ and $\sigma_8 = 0.8$, within a box of 100 Mpc a side. Mass and force resolutions are increased in the Lagrangian region surrounding the cluster, so that $m_{\text{DM}} = 2.1 \times 10^9 M_\odot$ and $m_{\text{gas}} = 3.2 \times 10^8 M_\odot$ for the mass of the DM and gas particles, respectively. The Plummer-equivalent gravitational softening is $\epsilon = 5 h^{-1} \text{ kpc}$ fixed in physical units from $z = 0$ to $z = 2$, while fixed in comoving units at earlier epochs.

In this Letter we focus on the effect of changing the

main ingredients which determine the content and distribution of metals in the ICM, namely the IMF and the feedback strength. The choice of such parameters for the different simulations, along with some results, are summarized in Table 1. Besides the standard IMF Salpeter shape (S55), $dN/d\log m \propto m^{-x}$, with $x = 1.35$, we also consider the flatter IMF by Arimoto & Yoshii (1987, AY hereafter), with $x = 0.95$, which provides a larger number of massive stars. Different authors (e.g., Finoguenov et al. 2003, FBB hereafter; Baumgartner et al. 2003, B03 hereafter) have suggested that an early population of very massive, metal poor stars should be advocated to account for the pattern of ICM abundances (cf. also Scannapieco, Schneider & Ferrara 2002). Therefore, we also consider an evolving IMF with the shape proposed by Larson (1999), $dN/d\log m \propto (1 + m/m_s)^{-1.35}$. Following FBB, we allow $\log m_s/M_\odot$ to linearly increase with redshift from -0.35 at $z = 2$ up to 1 at $z = 10$, being constant at $z < 2$.

As a first diagnostic for the ICM metal enrichment, we use the profiles of Fe abundance. We compare in Figure 1 the results of our simulations to those from the Beppo-SAX observations of 12 cool-core clusters by De Grandi et al. (2003). In the left panels of Figure 1 we show the effect of changing the strength of the feedback for the Salpeter IMF. Model A has a wind speed of $v_W = 520 \text{ km s}^{-1}$. Model B assumes somewhat weaker winds, while Model C assumes that the energy in winds is three times higher than that provided by SN, with the same wind velocity as in Model A once a three times larger amount of gas (i.e., $\eta = 6$) is ejected. As long as we assume that AGN activity in galaxies follows star formation (e.g., Boyle & Terlevich 1997, cf. also Cristiani et al. 2003), such an extra energy powering the winds can be interpreted as released by nuclear activity. All the models produce Z_{Fe} profiles (we define Z_{Fe} as the iron abundance by mass in solar unit, $X_{\text{Fe}}/X_{\text{Fe}\odot}$) which are steeper than observed at $R \lesssim 0.05 R_{200}$. At larger radii simulated profiles for Models A and B have a shape similar to the observed ones, although lower by about a factor two. An inspection of the age of stars associated with the central cD reveals that they are younger than those observed in real clusters, with signatures of significant ongoing star formation down to $z = 0$. This is also consistent with the large amount of stars found in the simulated cluster (see Col. 6 of Table 1), witnessing that feedback is not strong enough to inhibit recent star formation. The steep profiles of Fe abundance suggest that a significant amount of Fe in central regions has been produced quite recently, within an already formed cluster potential well, thus making difficult for winds to transport metals far from the star forming regions. This fact further confirms that a mechanism is currently missing in simulations to diffuse metals and quench star formation before most of the mass is accreted in the cluster potential well. By increasing the wind efficiency, as in Model C, star formation is heavily suppressed at high redshift. While this turns into a more acceptable value of f_* , it has the unwelcome feature of a too low ICM metallicity, with a quite steep gradient.

Using for Model D the AY IMF, with the same choice of feedback parameters as in Model A, provides a much larger energy release from massive stars. Correspondingly, the wind velocity is about twice as large and, probably, unrealistic. The resulting star fraction is acceptable, but with a larger

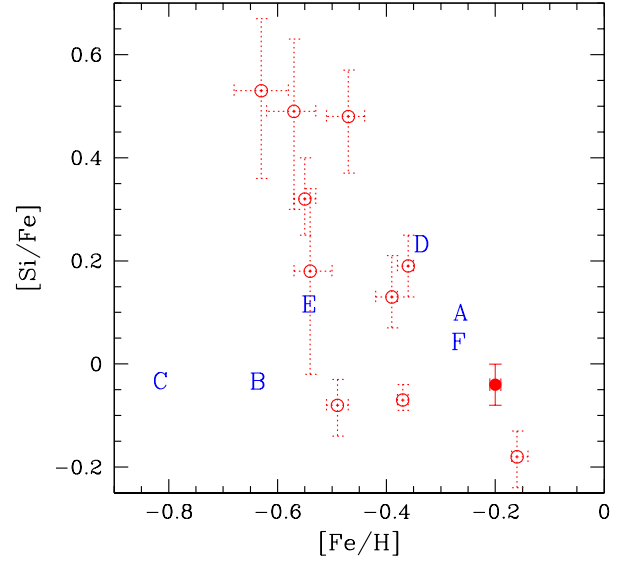


Figure 2. The comparison between the values of Silicon-over-Iron ratio vs. Iron metallicity found by Baumgartner et al. (2003) from their compilation of ASCA data (circles with errorbars), and those measured for the different runs of our Virgo-like clusters. Model labels are the same as in Table 1. The filled data point refers to the temperature bin appropriate for our simulated cluster.

amount of Fe released into the ICM, as a consequence of the higher IMF over most of the mass range relevant for SNIa. Reducing the χ parameter in Model E, to obtain wind velocity comparable to Model A, increases the resulting star fraction and the total amount of produced Fe (see Table 1). However, the weaker winds cause a large Fe fraction to remain in star-forming regions, being locked into stars instead of being diffused. Having a top-heavier IMF at high redshift (Model F) has again the effect of increasing the feedback efficiency. As for the Fe production and diffusion, its behaviour is similar to that of Model D, thought with ~ 30 per cent more Fe due to the higher IMF over the mass range relevant for SNIa.

In the upper panels of Fig.1 we show the profiles of $[O/Fe]$. Since Oxygen is mostly produced by SNII, $[O/Fe]$ is usually considered as a diagnostic for the relative role played by the two SN types. So far, robust measurements of the O abundance have been realized with the XMM-NEWTON GRS, and are limited to the very central regions of galaxy clusters. Gastaldello & Molendi (2002) and Matsushita et al. (2003) found $[O/Fe] \simeq -0.3$ around M87 out to about 60 kpc, which corresponds to $\simeq 0.04 R_{200}$ for our simulated cluster. On larger scales, the difficult detection of the OVIII emission line at 0.67 keV makes the determination of $[O/Fe]$ more uncertain, although values in the range between -0.2 and 0.2 seem to be preferred (see Renzini 1997 for a discussion). The negative gradients of our $[O/Fe]$ profiles are the signature of recent star formation episodes in the central region. This arises because SNII already had time to explode, while SNIa, which are generated by longer-living stars, still have to release Iron. As a consequence, the ICM for Models A and B turns out to be over-abundant in Oxygen, in the central regions, with respect to what observed for M87, while being consistent with data on larger scales. Assuming

an AY IMF provides a relatively larger number of SNII, thus exacerbating the problem of Oxygen overabundance.

As for the overall metallicity, we obtain emission-weighted Z_{Fe} values in the range 0.25–0.55, with the only exception of Model C, which produces a lower Fe abundance. It is worth noticing that, although Models A and F produces the highest $Z_{\text{Fe}}^{\text{ew}}$ values (see Table 1), they have different mass-weighted Fe abundances. In particular, the high $Z_{\text{Fe}}^{\text{ew}}$ of Model A corresponds to a fairly small mass-weighted value, the large difference being due to the steep profile of the Fe abundance. In their compilation of ASCA data, B03 find that Z_{Fe} tends to decrease with cluster temperature, with $Z_{\text{Fe}} \simeq 0.7$ for $T \simeq 3$ keV, down to $Z_{\text{Fe}} \simeq 0.3$ at $T \simeq 10$ keV (cf. also Renzini 2003, who claims a roughly constant $Z_{\text{Fe}} \sim 0.3$ over the same temperature range). Therefore, for our Virgo-like cluster we should expect a Fe enrichment which is sensibly larger than found in simulations. However, we note that the procedure of stacking X-ray spectra of clusters with similar temperature, as followed by B03, corresponds to assuming that all clusters having the same T also have the same metallicity, and, therefore, that the fairly large scatter observed is only due to measurement errors. Since some amount of intrinsic scatter is anyway expected, it is difficult to assess, with only one cluster simulated, how discrepant are our Z_{Fe} values with respect to the observed ones. Another feature of the simulated Fe production is that the ICM contains between about 25 and 40 per cent of the total amount of produced Fe, at odds with observational indications for $M_{\text{Fe,ICM}}/M_{\text{Fe,*}} \sim 2$ (Renzini 2003). This further suggests that a mechanism is still lacking in simulations to transport metals away from star-forming regions.

Unlike Oxygen, which is difficult to detect in the X-ray spectra of the hot ICM, Silicon is now detected for a fair number of clusters. Since a sizeable fraction of Si is produced also by SNIa, depending on the choice for the IMF, it could be a useful tool to investigate the relative contribution to metal enrichment from the two SNe types (e.g. Lowenstein 2003). In Figure 2 we show $[\text{Si}/\text{Fe}]$ vs. $[\text{Fe}/\text{H}]$ for our simulations, compared to the observational values from B03. Several of our runs produce a relative $[\text{Si}/\text{Fe}]$ ratio which falls on the correlation indicated by data, although the observed absolute Fe abundance for $\simeq 3$ keV clusters (marked by the filled circle) is significantly larger than that produced by several of our models. We note that the models better approximating observational data are A and F, which, besides providing a realistic emission-weighted Fe abundance, also produce an acceptable amount of Si.

As a word of caution, we note that the resolution of the simulations presented here could prevent the treatment of some physical effects, which may change final results. For instance, effects of dynamical stripping may play a significant role in removing metal-rich gas from cluster galaxies and, therefore, to enrich the diffuse ICM (e.g., Gnedin 1998; Tonizzzo & Schindler 2001). While tidal stripping should be well represented in our simulations, a proper treatment of ram-pressure stripping would require a substantially higher resolution in an SPH simulation. Aguirre et al. (2001) claim that ram-pressure stripping from galaxies of mass $> 3 \times 10^{10} M_{\odot}$ accounts for a small fraction of the ICM metal content. Furthermore, Renzini (2003) argues that, if ram-pressure stripping were efficient, then clusters with larger velocity dis-

persion should have a relatively higher metallicity, a trend which is not observed.

Furthermore, in order to have reliable estimates of the ICM metal enrichment, we have to make sure that our simulation has high enough resolution to provide a correct representation of the star formation history (see also Tornatore et al. 2003). We postpone a detailed study of numerical convergence of star formation and metal production within clusters in a forthcoming paper.

4 CONCLUSIONS

We have presented results from hydrodynamical simulations of the ICM, realized with a chemodynamical version of the GADGET code. We used a version of this code that, besides a fairly advanced treatment of star formation and feedback from galactic winds (Springel & Hernquist 2003a, SH03), also correctly accounts for life-times of different stellar populations, as well as for metal and energy release from SNIa and II (Tornatore et al. 2004, in preparation). By simulating one single cluster, having temperature of about 3 keV, we looked at the effect of feedback strength and IMF on the resulting metal production. Our main results can be summarized as follows.

- (a) Among the considered models, using a variable IMF (Model F) provides an acceptable amount of Fe mass, as well as $[\text{Si}/\text{Fe}]$ and $[\text{O}/\text{Fe}]$ ratios, in fair agreement with observations. Using a Salpeter (1955) IMF turns into a lower amount of Fe mass and to supersolar values of $[\text{O}/\text{Fe}]$ in the central cluster region, at variance with observations. An Arimoto–Yoshii (1987) IMF provides an even larger Oxygen abundance, as a consequence of the larger number of SNII.
- (b) Gradients of the Fe abundance are always steeper than observed in central cluster regions, $R \lesssim 0.1 R_{200}$, while the Z_{Fe} profiles on larger scales fall below the observed ones, by an amount which depends on the feedback strength and on the assumed IMF.
- (c) Besides the effect of the IMF, the oversolar value of the $[\text{O}/\text{Fe}]$ ratio found in central regions for several models could be due to the presence of a significant recent star formation in central cluster regions. Because of such an excess of recent star formation, not shown by observational data, the stars in our simulations lock a large fraction of metals (see Table 1).

Our analysis confirms that the observed pattern of metal enrichment of the ICM is deeply connected to the past history of star formation in clusters and to the feedback scheme that should release energy and heavy elements into the diffuse medium. The fairly steep gradients of the Fe abundance and the signature of recent star formation consistently indicate that our simulations are missing a feedback mechanism, which should quench star formation and spread metals at an early enough epoch, when the proto-cluster potential well is still shallow enough not to retain the produced heavy elements. We verified that this feedback cannot be easily implemented by resorting to SNII and Ia. Neither increasing the strength of the feedback nor changing the IMF helps in restoring a better agreement with the observed profile of the Fe abundance. In our opinion this is a non-trivial result, since it has been obtained in the frame-

work a rather advanced scheme for star formation and SN feedback (SH03), which is otherwise quite successful at accounting for the pattern of cosmic star formation (Springel & Hernquist 2003b). In turn, this suggests that other energy sources, such as AGN, should be called into play to regulate the cooling structure of the ICM and determine its chemical composition.

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